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IMPROVING DOD MAINTENANCE THROUGH BETTER
PERFORMANCE AIDS

Thomas C. Rowan

Information Concepts, Incorporated

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Final Report - Article 1-d

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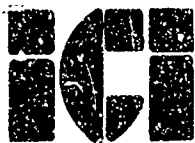
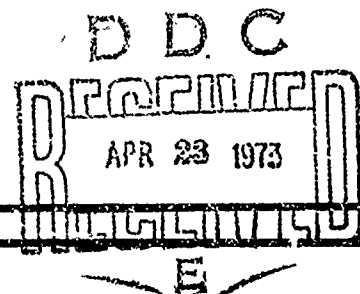
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<p>This report is concerned with the technical documentation used by maintenance personnel, and in particular job performance aids, that is, documents or devices that give precise step by step directions to perform a task or otherwise furnish the technician all the relevant information he needs in a compact form. A review is made of past research and current projects in DOD and elsewhere on maintenance aiding through innovations in format and content of maintenance documentation. Problems in evaluating this research and in implementing proven techniques are discussed. Recommendations are made, with respect to additional research and system demonstrations needed, areas for implementation and potential savings in changing training and personnel assignment practices.</p>			

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THROUGH BETTER PERFORMANCE AIDS

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SUMMARY

DOD spends on the order of \$20 B annually for maintenance, of which more than half is for personnel. There are indications that there is room for major improvement in the performance of maintenance with potential for reducing costs and increasing equipment availability. Such indications include high removal rates of non-failed components (on the order of 30%) and large disparities in the costs of maintaining similar equipment by different organizations. Although considerable pressure has developed in the hardware area for improvement in maintenance including stressing reliability and maintainability as design criteria and developing automatic and built in test equipment, little attention has been given to improving information transfer to the technician on the job.

Numerous studies on the format and content of maintenance information indicate that faster and better maintenance can be done if technicians use job performance aids, that is, documents or devices that give precise step-by-step instructions for each task or otherwise present in a concise and consolidated manner all information relevant to that task.

DOD has spent less than \$5 M to date and is spending considerably less than \$1 M annually to improve this "people" part of maintenance. The low level of R&D that has been

accomplished over the past several years indicates a large potential for improving maintenance and reducing both maintenance and training costs. More specifically the results indicate a potential to:

a) Reduce repair time and false removals and improve equipment reliability.

b) Significantly reduce (up to 75%) the training required for inexperienced personnel to perform accurately routine maintenance tasks.

c) Productively utilize personnel of lower ability levels.

d) Achieve the above at costs for maintenance aids comparable (within 20 - 25%) to those now being expended for conventional technical documentation.

Problems within DOD which must be solved for the potential improvement and savings to be realized include:

a) Lack of visibility and focus on the costs of improper maintenance.

b) Institutional resistance to change and a lack of a sense of urgency to try new approaches in maintenance and in maintenance training.

c) Current fragmented and inadequately supported R&D efforts to demonstrate the improvement potential.

d) Lack of focal points in OSD and the military departments responsible for innovating and measuring improvement in the field.

In order to address these problems:

a) OSD and the military departments must establish focal points with a commitment to achieve a technology transfer from the R&D level to the field and to measure the results.

b) The R&D must be adequately supported, perhaps at a level of \$4-5 M per year across DOD. The principal funding requirement is to plan, conduct and measure the results of several large scale field demonstrations of sufficient scope and time duration to resolve issues of cost, environment and attitude.

c) There must be a commitment at the top levels of OSD and the military departments to support major demonstration programs which cross the lines of systems, logistics and training and in areas which have a natural institutional resistance to change.

More specifically, the following summary recommendations are given below based on material developed in the body of the report:

System Demonstration

There is a need for a program of definitive demonstrations to settle the main issues in the area and to provide the needed impetus for implementation of those features that are effective in a real operating environment. The needed demonstrations should be conducted with each of the military departments being involved.

(1) The proposed but unfunded Air Force project "Innovate" should be enlarged and carried out. This project will compare conventional technical orders, decision aids and fully proceduralized job performance aids (JPA's) and will provide answers to the questions of whether brief technical training is adequate with JPA's and whether JPA's alleviate the cross-training problems within a specialty.

(2) The Army's "Low Cost Ownership" Program on the improvement of military technical information transfer methods should be supported and funded as a three year experiment. This effort will analyze information presentation approaches in terms of their application to commodity groups - aircraft, combat vehicles, etc. - and will select the best approach or combination of approaches for each commodity group. Packages will then be demonstrated for several military occupational specialties for maintenance up through the depot level.

(3) The Naval Air Systems Command's MIARS and TRUMP systems should be accelerated and considered for Navy-wide use. MIARS is a microfilm system with hard copy compatibility that involves the reorganization of technical data into "work packages" that cut down the time that technicians must spend searching through manuals. It offers the capability of being the vehicle for introducing improvements in content such as job performance aids, once these improvements are accepted. TRUMP is a system now in procurement for automatically updating MIARS.

Management:

(1) Focal points should be designated in OSD and in each of the military departments with responsibility to deal with the R&D, systems, logistics, and training efforts needed for the large scale demonstration program.

(2) There should be fiscal visibility and management focus for the R&D program for maintenance aids. A Program Element should be established for each military department to consolidate the efforts.

(3) In order to coordinate the overall DOD efforts, there should be a tri-service review of current activities and plans in the maintenance aid area. A committee should be formed or an existing one directed to review the ongoing activity, particularly the planning of major demonstrations and the utilization of the results of those demonstrations. Formulation of an ARPA effort similar to the CAI program initiative should be considered.

(4) For an interim period of two to three years, OSD, specifically OSD (I&L) and DDR&E, should review the maintenance aids approach and funding proposed for new weapon systems and should stimulate the application of innovative approaches and funding support for these.

(5) The military departments should initiate analyses on the economics of production and utilization of improved maintenance aids. These should include the comparative costs

of alternative format and content (e.g., JPA's, SIMMS, conventional manuals) as well as media (books, microfilm, video cassette).

(6) DGD should institute, through the military departments, an analysis of the costs of improper maintenance (to include such factors as fake removals, spares, shipping, etc.). This data should be included in a broad analysis of the economics of applying better maintenance aids and information systems - to include training costs, personnel costs, and equipment costs.

Systems Application:

(1) Non-troubleshooting fully proceduralized job performance aids -- job guides -- should be developed for all new weapons systems. These will be primarily oriented to routine maintenance tasks. This should be done in accordance with specifications requiring task analysis.

(2) Job guides should be developed for selected portions of systems now in the inventory, based on a review of high cost areas.

(3) Information systems other than books such as audio-visual cassette and film systems to provide system overviews, to introduce equipment modifications and to explain difficult procedures should be applied.

(4) For major weapon systems, microfilm reader printers which include job guide formatted materials should be used

both for economic update and facility of information access.

Research and Development:

(1) FEFI/TAFI (Flight Environment Fault Indication/ Turn Around Fault Isolation), a troubleshooting system for the DC-10, should be examined for possible military application.

(2) Aids useful at different skill and experience levels and aids that have training objectives should be developed. The promising Navy sponsored research on "families of aids" should be extended so that multipurpose documentation suitable for experienced as well as inexperienced technicians can be developed with consideration also given to the inclusion of OJT material.

(3) Computer supported audio-visual presentation systems should be studied as potential sophisticated troubleshooting aids making possible dynamically optimized troubleshooting strategies.

(4) Studies should be made of the influence that system characteristics such as modularity or degree of built-in testing have on the type of aids appropriate for a system.

PERFORMANCE AID TECHNIQUES

Maintenance accounts for a large portion (20-25%) of the total DOD budget and even a small percentage decrease in this area would represent substantial savings. Over the past ten years DOD has put much emphasis on hardware approaches to better maintenance including more attention to reliability and maintainability as design criteria and the development of automatic and built-in test equipment.

One important area has, however, received very little attention and that is the area of maintenance information. The conventional technical manual systems have existed without major change for decades. Some gradual improvement has occurred but there has been no innovative thrust to do something significantly better for the "people" part of the maintenance problem. Within the R&D community there have been a number of small-scale experiments and demonstrations of new ways of presenting information that enable technicians to perform faster and more accurately, and with less training. Although some of these techniques appear to have the potential for greatly reducing cost of maintenance perhaps by 30% or more and improving equipment availability, there has been relatively little application of these research results outside of the laboratory. This report discusses what has been done in developing alternatives to the conventional technical manual and recommends several steps that DOD should take in the area.

The report is concerned primarily with what have become known as performance aids, that is, devices or documents that contain guidance information that helps the technician perform a particular job at hand, and are "people" rather than equipment directed. The aid may be a very specific step-by-step set of directions that require no decisions to be made or it may be something that gives a more general picture of the system and assists the technician in deciding what to do next. A large number of approaches, and acronyms, have arisen but most of the research has tended to focus on the specific or fully proceduralized aid for non-troubleshooting tasks with the differences in approach appearing in the area of troubleshooting aids.

The objective of all the approaches has been to provide in one package simple, complete and current information to the technician, without the need for cross referencing and retention. Fully proceduralized performance aids break up a task into easily remembered steps and present unambiguous directions using simple English and relevant illustrations. Well designed aids are based on a careful analysis of the task the technician actually has to do and take into consideration the amount of training and experience of the personnel who will be using them. While one would assume that the current maintenance documentation would do just this, it rarely does. The process by which documentation is produced

often means that the maintenance manual is written before the equipment is produced and is not based on what the technician actually must do to repair it. In analyzing maintenance actions required for the doppler radar system of the C-141, the Air Force found that the isolation and repair of one malfunction required reference to 165 pages of 8 documents. If no false moves were made, 41 changes in document location were required.

Fully proceduralized aids have been developed for troubleshooting tasks, but most of the research on troubleshooting has involved decision aids, devices for helping the technician understand the system or subsystem and formulate a strategy for isolating the fault or faults. Most of the decision aids have included variations of the Maintenance Dependency Chart (MDC), a device which can vary greatly in complexity and which indicates, for different system modes, what elements are interrelated.

Jobs performance aids research has been summarized a number of times; one of the most recent summaries is in Price et al (1971). Others are Foley (1969), Chalupsky and Kopf (1967) and Shriver (1966). For the most part these have been descriptive summaries rather than critical reviews. An attempt will be made here to evaluate the quality of selected research projects in order to assess the present claims put forward for this general approach to maintenance documentation

and for particular aids. All known reports that included laboratory or field test results will be reviewed; in the interests of brevity only the highlights of each study will be covered. More detail can be found in the specific references given or in the above mentioned reviews. The studies are summarized in Table 1.

TABLE I
Experimental Comparisons of Innovative Job Aids
Versus Conventional Documentation

<u>Concept</u>	<u>Year</u>	<u>Equipment</u>	<u>No. of Subjects</u>	<u>Results</u>	<u>Remarks</u>
FORECAST	1958	Anti Aircraft Fire Control System	37	Equivalent performance	60% less training time
	1959	"	16	40% improvement in perform- ance. stat. signif.	50% less training time
	1963	LORAN	98	Three times more faults identified. stat. signif.	Same training time
JOBTRAIN	1962	Comm. Equip.	39	Equiv. performance	50% less training time
MAINTRAIN	1963	NIKE AJAX Radar	16	42% more malfunction found in 41% less time	10% level of con- fidence was used
SYMPTOM- COLLECTION Manuals	1964	HAWK Radar	84	80% vs. 40% isolation of faults. stat. signif.	Experimental group was higher in aptitude
NIKE X MDS (A-VIS)	1964	Target tracking radar	15	Programmed material superior to conventional. Visual-only mode 27% more effective. Programmed TM 19% more effective. signif.	Results were a mixture of content and mode of pre- sentation
SIMMS	1964	Radar	42	SIMMS gp. performed at 96%, controls at 70%	
	1971	SRC-20 Radio	178	Low trained grp. better with SIMMS high trained group better with conventional	Study was poorly designed and executed

<u>Concept</u>	<u>Year</u>	<u>Equipment</u>	<u>No. of Subjects</u>	<u>Results</u>	<u>Remarks</u>
BFIC	1966	Electronic Modules	80	Exper. group performed in 1/3 the time and made 1/5 the errors. Stat. signif.	High and low exper. and aptitude groups were matched
PIMO	1968	CL41A	36	Apprentices performed non-troubleshooting tasks error free. Experienced technicians did troubleshooting in 11% less time and with 1/5 the errors. Stat. signif.	Only experienced technicians did troubleshooting
Fully Proced. Trouble- shooting JPA's	1968	Maintenance Task	61	High School students performed similar to exper. technicians	Dubious assumptions made to justify performance
British Algorithm	1969	Nav. Equip.	5	Ave. diagnosis time fell from 90 to 31 minutes	No statistical treatment reported
Non-trouble shooting JPA's	1970	F-4J	52	Inexper. technicians using guides performed 30% better than exper. using manuals Stat. signif.	Exper. personnel also did better than guides
Fully Proced. JPA's Maintenance Dependency Charts	1971	UH-1H Helicopter	90	USAF technicians better with JPA's than TM's. Apprentices better with JPA's than experienced technicians were with TM's. MDC's were inferior to JPA's and TM's. VNAF experienced technicians performed equally well with all aids, apprentices did better with JPA, outperforming experienced technicians.	Study not published. No statistical significance indicated in summary. Original aids full of errors

<u>Concept</u>	<u>Year</u>	<u>Equipment</u>	<u>No. of Subjects</u>	<u>Results</u>	<u>Remarks</u>
SAFEGUARD MDS Phase four test	1972	Radar Return Generator	13	Technician performance not signif. diff. from test standards	Procedure used to specify standards was questionable
Non-Trouble shooting JPA's	1972	Mobile electric power plant	26	Inexperienced made no more errors	JPA's had to be validated before test could proceed

REVIEW OF PERFORMANCE AID RESEARCH

EXPERIMENTS AND FIELD TESTS

FORECAST, which resulted from early HumRRO research, is an approach to systems analysis, training and performance aids. The aids produced are decision type aids such as troubleshooting block diagrams, waveform guides, and blocked schematics. These aids are used in the training program to convey system understanding and to teach troubleshooting. In 1958, (Shriver, 1960 - Report #63) an experimental 12 week FORECAST training program was conducted for Army M-33 anti-aircraft fire control system electronic technicians. A comparison of 20 experimental subjects and 17 students from the regular 30 week course was made using 89 troubleshooting tasks administered over a nine day period. The mean test score for the experimental group was 140.8 and the standard group 142.9. With standard deviations of 9.2 for the experimental group and 11.7 for the standard group, the difference can be considered slight. Of importance, of course, is the difference in training time - 12 weeks versus the standard 30 weeks. The relative contribution to performance of the training program versus the troubleshooting aids cannot be deduced. In a later study students who were given additional practice with a mock-up of the real equipment performed significantly better than the earlier groups. In this case, the effects of the experimental training, the performance aids and the use of the mock-up are confounded.

Another test was conducted in 1963 with 98 subjects using Navy Loran equipment. Twelve subjects had conventional training and manuals; the remaining had FORECAST training and manuals. The FORECAST subjects identified three times as many malfunctions as the conventional subjects.

JOBTRAIN was also the result of research by HumRRO. Under this concept a comprehensive failure-effect analysis is made and symptom patterns developed. The resulting job aid is in paragraph form with branching to subtests when bad effects are found. An experimental training program was developed to be used in conjunction with the aid. The aid and training course were compared with traditional documentation and training in 1962 at Fort Gordon, Georgia, using radio relay and carrier repair technicians (GEBHARD, 1970). Nineteen standard trainees (regular 25 week school, conventional documents) and twenty-one experimental trainees (JOBTRAIN course of 11 weeks and the JOBTRAIN aid) were given 18 problems to troubleshoot and were also tested on their ability to align, remove, replace, etc. Variables such as education, electronic aptitude and civilian experience were controlled by matching subjects. The results of the tests were that the groups performed similarly. No statistically significant differences were found and the investigators concluded therefore that JOBTRAIN training and

aids were as effective as traditional training and manuals and that a 50% reduction in training time can result from the JOBTRAIN approach. A problem with such a conclusion is that in terms of statistical theory, failure to find a difference does not prove that no difference exists. Practically speaking, however, the results are suggestive. One is left with uncertainty about the relative importance of the experimental training course versus the job aid.

MAINTRAIN, (Rogers & Thomas, 1963) another HumRRO project, was an effort to develop an improved manual for use by trained technicians in troubleshooting complex electronic equipment. Included in the manual were an improved index to troubleshooting instructions, data flow diagrams, and chassis function diagrams. The manual was tested by having recent Missile School graduates troubleshoot 44 faults with Nike Ajax Missiles. Subjects were matched on the basis of Air Defense School grades and divided into two groups of eight. One group used the MAINTRAIN Manual and the other conventional manuals. The experimental group located 42% more electronic malfunctions in 41% less time. These differences are significant at the .10 level of confidence. Why such a confidence level was used is not indicated. The number of electronical faults found by the two groups was not statistically different.

In 1964-65 HumRRO developed a procedure oriented training program for HAWK Radar Mechanics (HumRRO 1969). As part of this project, symptom-collection manuals were developed which were essentially proceduralized troubleshooting aids. The manuals were used in training a 30 man experimental group. In a test, experimental students using the symptom-collection manuals (and traditional documentation) isolated 80% of the defective chassis while the control group using only traditional documentation isolated 40%. This difference is statistically significant. Further analysis indicated that the utility of the symptom-collection manuals was greatest for the most difficult malfunctions. The experimental and control groups were quite comparable in age and education. Their aptitude scores, however, differed; the average general technical aptitude (GT) score for the experimental group was 123.4. The averages for the two control groups were 115.8 and 118.5. Whether this accounts for the difference in performance is unknown, but the possibility weakens the impact of the study.

The SAFEGUARD Maintenance Data System (MDS), to be discussed later, derived from earlier work with the NIKE X system performed by Bell Telephone Laboratories. In 1964, a data system called A-VIS, (Audio - Visual Information System) was tested at White Sands Missile Range (USATECOM, 1964). As the name implies this is an audio visual system

and the test consisted of comparisons of modes of presenting maintenance information. The content used consisted of both logic-tree trouble analysis aids and decisions aids such as functional block diagrams. This JPA-like content was presented in a combined audio-visual mode, an audio mode (with the visual portion in hard copy), a visual mode (audio portion in hard copy) and a hard copy mode, termed programmed TM. All of these modes of presentation were superior to technical manuals (acutally TM-like material since no TM's existed for this R&D equipment). Of the presentation modes the visual-only one was superior. In terms of a performance index created by the investigators, the visual-only mode was 27% more effective than technical manuals. The programmed TM was 19% more effective.

Shriver (1966) reports in his review an evaluation of SIMMS that was carried out for the Coast Guard in 1964 on a radar with 42 subjects. The SIMMS group identified the three malfunctions used in the test 96% of the time and the conventional group identified them 70% of the time. The SIMMS group took half as much time to troubleshoot.

Research Triangle Institute (Krohn, et al, 1971) under contract to Naval Ships Engineering Center compared SIMMS and conventional documentation for the AN/SRC-20 radio set

at three Navy C-school locations involving 178 technicians. Each school had classes on the SRC-20, some based on the conventional manual and some on the SIMMS manual. Identical instructional material, tests and troubles were used in each school. Data on troubleshooting performance were collected for one year by instructors. Analysis indicated that data from the different schools could not be combined because different standards were used by the instructors in collecting the data. Because of the fact that the students were not matched for relevant characteristics when assigned to the two versions of the course, the results were hard to interpret. The investigators concluded that technicians with medium training performed similarly with either manual. Those with little training did better with SIMMS and highly trained technicians did better with conventional documentation. In the discussion, the investigators state that other factors such as training and experience may have biased the results. For example, in the low experience SIMMS group, which did better than the corresponding conventional group, 16 of the 28 technicians had prior experience with the SRC-20 as compared to 4 of the 14 conventional technicians. This and other weaknesses in the study make the results inconclusive.

Binary Fault Isolation Chart (BFIC), a concept developed by Westinghouse, is a troubleshooting logic-tree using a



flow chart format with standard geometric symbols. An experiment was conducted in 1966 with 80 Westinghouse employees, matched in experience and aptitude (Westinghouse, 1966). Half the group was given a BFIC for use in troubleshooting a moderately complex electronic module. The others were given traditional documentation. The experimental group performed in one-third the time taken by the control group and made one-fifth the errors. The results were significant at the .01 level of confidence.

Project PIMO (Presentation of Information for Maintenance and Operations) has been the most extensive effort in the job aid area. It was carried out by Serendipity Inc. for the Air Force from 1964 to 1969 and is described in an eight volume final report (Serendipity, 1969). PIMO consists of fully proceduralized aids for non-troubleshooting maintenance tasks (job guides) and simplified maintenance dependency charts for troubleshooting. The guides used a fixed format and syntax, and a preferred verb list with a limited number of steps per page. The concept is often associated with format - pocket size books with pictures and text on facing pages - but like the other aiding concepts, its content necessarily must be based on careful task analysis.

A large scale field evaluation was carried out primarily at Charleston AF Base in 1968 using aids produced for organizational level maintenance on the C-141A. PIMO booklets, an audio visual version of PIMO and traditional documentation were compared using both experienced and inexperienced personnel. Perhaps the most noteworthy result of the evaluation was that in over 1,000 observations of performance with PIMO no error was observed.

In non-troubleshooting activities, experienced personnel using standard operating procedures had shorter maintenance times than they did when using PIMO. Analysis of the data indicated, however, that time to repair using PIMO was reduced with repetition and approached the conventional time.

Apprentice technicians performed non-troubleshooting tasks without error using PIMO in slightly more time than the experienced technicians did when they used PIMO. The PIMO report authors point to the practical significance of the apprentices being able to perform maintenance error free using PIMO even though they were slightly slower. It was assumed that their times would also be reduced with repetition as they learned the equipment and the aids.

One of the objectives of the field test was to compare the audio-visual PIMO mode with the hard copy mode. The results were that performance times using the booklet were slightly shorter but the difference was statistically

significant only for Remove Activities. The authors concluded that the modes were equivalent and thus booklets, being less expensive, were preferable. It is worth noting that considerable difficulty was experienced during the test with the audio-visual hardware which was reflected in the opinions expressed by participants. What impact this had on results is unknown.

Only experienced personnel were used in testing the PIMO troubleshooting aids (TSA). There was an 11% reduction in time using PIMO versus standard procedures; this is statistically significant. Forty troubleshooting actions were performed with PIMO with one error, a zero-defect removal. Forty-one actions were taken in the standard mode with 12 errors; five of these were zero-defect removals. These differences were not tested for statistical significance, but are interesting considering the impact a reduction of 5 to 1 in zero-defect removals would have in terms of spares consumption.

Applied Science Associates, under contract to AFHRL in 1968 compared 20 naive high school students given 12 hours training with 41 Air Force technicians having several years training and experience in electronics (Elliott & Joyce, 1968). The average technician was 27 years old, had attended three Air Force schools and was between grade E-4 and E-5. The

mean AQE electronic aptitude score was 83 for the technicians, 73 for the high school students. The task was within-stage troubleshooting on the Maintenance Task Simulator (MTS-2). The students used fully proceduralized aids and the technicians tech-order like data. Unfortunately the tasks given the two groups differed. The students were given only one chance to solve each problem while the technicians were given a time limit of 90 minutes. The student mean time to completion was thus the average of the times taken to complete the specified procedure once. Some of the technicians took the full 90 minutes, thus greatly influencing their mean time with the result that it (32.7 minutes) was greater than the students' (27.5 minutes). On the other hand the students made 2-1/2 times more errors: if the module did not function properly at the end of the checkout procedure, the student wasn't allowed to go back to find where he erred, whereas the technicians were limited only by time.

The investigators tried to estimate what the results would have been if the students had been allowed a second try. If the admittedly dubious assumptions made in this correction were valid the results for the student and technician groups would be very similar. It is the present writer's opinion that these assumptions, for example that the probability of error on the second trial would be the same as on the first, are so untenable that the study is

entirely inconclusive. One might ask why a comparison of naive high school students and seven year experienced technicians was made. The student data were actually a part of an earlier study of aptitude and performance. Apparently it was decided later that the high school performance should be compared to that of experienced technicians who were being tested using conventional manuals in order to generate speed and accuracy standards. Even though the investigators' conclusion that there was no substantial difference between the groups is believed unfounded, it is noteworthy that students with only 12 hours of training were able to perform as well as they did. It seemed likely that their performance would have been even better with a little more training. For instance, the students' most frequent error was component orientation, such as interchanging the base and collector leads of a transistor. Another contribution to student error was cold solder joints. If one adjusts the data for these two types of errors, the student error rate comes down almost to that of the experienced technician.

A fully proceduralized fault diagnosis algorithm developed by the British Air Force was tested over a five week period in 1969 with five technicians performing with and without the aid. (Stenner and Robinson, 1969). The

mean time to diagnose faults was 90 minutes without the guide and 31 minutes with it. In nearly half the non-guide cases, components were changed in error. With the guides only one component was wrongly changed in 30 trials. No statistical tests were reported.

Serendipity Inc., under contract to the Naval Air Systems Command, conducted a field test of fully proceduralized non-troubleshooting aids involving 19 organizational maintenance tasks on the F-4J in 1970 (Post, 1970). Fifty-two technicians were involved with a total of 635 maintenance actions performed. The test was conducted onboard the USS Saratoga and at the Naval Air Station, Oceana. Portions of the existing Maintenance Information Manuals that were relevant to the faults used in the test were collected, checked for accuracy and packaged for each maintenance task so that the content of the traditional material would be as available as the job guides. In the tests, experienced personnel had the option of using or not using the excerpts from the manual; inexperienced personnel were required to use them. Using existing procedures, experienced personnel performed satisfactorily (in terms of meeting quality assurance standards) 74% of the time and inexperienced 63% of the time for an average of 68%. While using the job guides experienced personnel performance was 100% and inexperienced 94% for an average of 97%. Thus, inexperience personnel performing

with job guides were 30% better than experienced personnel using existing procedures.

In terms of procedural errors, experienced personnel using existing procedures had 14%, with job guides 4%. The figures for inexperienced were 14% and 6%. This is an overall improvement of 64%. All of the above results were statistically significant.

An additional comparison was made of performance over repeated trials with and without the aids by inexperienced personnel doing operational checks. The performance with the manuals was fast and stable from trial to trial, but the error rate was high and remained so over trials. The error rate with job guides was very low and the time to perform diminished over trials and approached the time taken without the aids. It was apparent that the manual-supported performance was rapid because of the omission of critical steps. The learning effect found with the aids was similar to that found in the PIMO studies.

JPA's were developed for the UH-1H helicopter in the Vietnamization program for the Air Force by XYZYX and were evaluated in 1971. Fifty-four U.S. and 36 Vietnam technicians were involved. Some were experienced (at least one year experience on the UH-1H), some were apprentices (trained but little or no experience), and some were

novices (no training or experience). The results for non-troubleshooting tasks were similar to earlier studies. Experienced USAF personnel did slightly better with JPA's than with conventional documentation (92% completion vs 88%) and apprentices did much better (95% vs 68%). For novices the figures were 61% vs 33%. The VNAF experienced technicians performed equally well with technical manuals or JPA's and the VNAF apprentices performed somewhat better with JPA's.

For troubleshooting tasks, fully proceduralized JPA's, maintenance dependency charts (MDC's) and technical manuals were compared. Performance of experienced USAF technicians was better with JPA's in contrast to TM's (100% vs 83%). For apprentices the figures were 100% vs 61% and for novices 56% vs 44%. For each group, MDC performance was inferior to fully proceduralized JPA's or TM's. Both groups of VNAF technicians (there were no novices tested in Viet Nam) performed quite well (80+ correct) on troubleshooting tasks with all three forms of documentation. Apprentices performed error free with fully-proceduralized aids and at about 85% with TM's and MDC's, which was somewhat better than experienced technicians.

A major finding of the study was that the original UH-1H JPA's were virtually unusable because of errors. This was attributed to a lack of a thorough task analysis, which had to be done to correct the aids used in the study.

This study was never published by the Air Force and the above information is from a two-page summary obtained informally. It is consequently difficult to render any judgment about its validity. The results with USAF personnel are consistent with other experiments except for MDC's being inferior for troubleshooting. The results with Vietnamese subjects, however, are confusing and may be due to the possibility mentioned in the summary of unavoidable contamination of some of the data obtained in operational environments.

The SAFEGUARD Maintenance Data System (MDS) is a large (680,000 frames) microfilm system designed to support maintenance and operation of SAFEGUARD. MDS uses task oriented step-by-step procedures with illustrations for linear procedures such as start up, adjust, check, lubricate, disassemble and assemble. Troubleshooting is supported by logic tree frames and associated simplified functional block diagrams. Additionally the system contains other support information such as signal flow diagrams, repair parts data, and location information. The reader-printer utilized has a keyboard to access any one of the frames on a 16 mm rolled film cassette. Each cassette will have approximately 1,000 frames.

The U.S. Army SAFEGUARD Logistics Command has conducted four phases of a five phase test program of MDS. The early phases were primarily concerned with data verification procedures and viewing equipment. The fourth phase, conducted in October and November 1972, tested the adequacy and effectiveness of the MDS data package produced by the Raytheon Company to support operation and maintenance tasks on the Radar Return Generator (RRG).

Earlier phases of the test program used MTTR's as test standards with generally positive results. Phase IV compared the performance of military technicians with Raytheon engineers. Because of a number of differences in the conditions under which the two groups performed, it is the writer's opinion that the main results of the experiment were inconclusive. However, comparisons of technician performance with available technical logistics data repair times were favorable, indicating that the system could be maintained satisfactorily using MDS. Throughout the test phases data accuracy was a problem; in some cases tests could not be conducted until the data were corrected.

In contrast to other aids developments the MDS was designed to meet stringent MTTR goals with experienced technicians. MDS is the only example of a large weapon system which uses proceduralized aids extensively.

In 1972, the Naval Weapons Engineering Support Activity, at the request of Naval Air Systems Command, tested the effectiveness of fully proceduralized non-troubleshooting aids that had been produced by the XYZYX Corporation for the NC-8A Mobile electric power plant (Horne, 1972). The data was collected over a six months period and consisted of 297 non-scheduled intermediate maintenance actions performed by 26 technicians. In order to determine the performance of "inexperienced" personnel, electronics maintenance actions were assigned to mechanical technicians and vice versa. The results indicate that inexperienced personnel using JPA's made no more errors than experienced personnel using conventional documentation. Experienced personnel took longer using JPA's than they did with conventional manuals but they performed error free. This latter result was statistically significant. The comparison of inexperienced technicians using JPA and experienced technicians using conventional manuals is again a matter of finding no significant difference and assuming that none exists.

Two other features of this study merit comment. Since the aids were non-troubleshooting ones, inexperienced personnel had to be directed to the procedure to be followed. An experienced technician did the troubleshooting and then assigned one of the inexperienced men a task. Indications were that an experienced troubleshooter could keep at least

four inexperienced men occupied doing maintenance using JPA's. The work load was such that this span of control could not be tested; it may be wider..

Before this study could be conducted it was necessary that the JPA's be further validated. They had been produced without a specification having been imposed on the contractor but they had been "desk-top" validated before delivery. A number of errors were found when the material was reviewed by experienced technicians before the test. However, even after the aids had been judged to be complete it was clear that "hands-on" validation was necessary to make the aids usable by inexperienced personnel. This is a circumstance quite frequently found during the review of JPA studies. As in a computer program, the smallest error in a JPA may cause trouble; because of their inherent vagueness conventional manuals escape this criticism.

OTHER DOD PROJECTS

In additon to the above, there have been a number of performance aids developed but not formally tested. The largest number have been procured by the Air Force for Vietnamization; in addition to the UH-1H aids were prepared for the CH-47, C-7A, three jet engines, a refueling vehicle and two fire-trucks. JPA's for organizational, intermediate and depot maintenance are being produced for an electronic system called Seek Point.

The Air Force Systems Command has developed a specification (MIL-J-8332) for use in the procurement of bilingual JPA's and an "Americanized" version of the specification that has not yet been officially adopted. These specifications, which will be discussed again later, require a process of careful analysis which is designed to avoid the errors and lack of completeness in JPA's.

In the Spring of 1972, the Air Force conducted a project at Altus AFB in which 16 recruits with only basic training were given four weeks of training in how to maintain the AN/APN-147 and AN/ASN-35 navigational radar system using fully proceduralized JPA's. After training, the airmen participated in a demonstration where they were given 14 problems. The report of the results of the demonstration has not yet been published but one observer has written that the demonstration went well and that most of the visitors appeared to be favorably impressed.

The Altus demonstration was a preliminary part of an experiment involving experienced technicians and novices and JPA's, SIMMS aids and traditional documentation. This experiment, which will be discussed later, has not been funded.

The Army has developed aids for the following systems: armament pad for aircraft, search light, storage battery, tank engine, gasoline engine water pump and a tow launcher.

These particular systems resulted from the commodity commands having been directed to produce draft aid material in the format specified in the AFSC specifications. It is likely that these systems were chosen for their simplicity since no funds were allocated for the efforts. The final aids were developed inhouse by AMC for all but one of the systems; LTC developed the other. According to the Army, only the format standards were followed; no attempt was made to do the task analysis called for by the AFSC specification. The aids were produced from material in the technical manuals and no "hands on" validation was done. Continental Army Command and Combat Developments Command have been asked to evaluate the aids and reports are expected in the Summer, 1973.

The Army scheduled an effort beginning with a planning phase this fiscal year in which information presentation techniques will be reviewed in the context of differing environments, training levels and equipment complexity. Aids, including the possibility of different combinations of techniques, will be developed and tested. Although a plan exists for a major series of demonstrations extending over several years, funding is not yet firmed up.

The Naval Air Systems Command has procured fully proceduralized JPA's in accordance with the AFSC specification for four subsystems of the LAMPS, a destroyer based

helicopter. These subsystems were chosen because they are high maintenance areas and present training problems. A total of \$100,000 was spent with three contractors, Kentron, a subsidiary of LTV, XYZYX and Westinghouse. All but one of the systems have been completed and are being verified on a sampling basis only, because of lack of funds.

The Naval Air Systems Command has in process the development and test of fully proceduralized JPA's for the AQA-7 sonar subsystem. A 12-week training program based on the JPA's will be developed and two inexperienced groups differing in aptitude will be trained to maintain the equipment. A field demonstration will then be made.

Navair has also sponsored research on innovative job aid concepts (Post and Price, 1972). The investigators point out that most research in job aids has concentrated on ways to assist users at a given level of aptitude and experience to perform in minimum time consistent with accuracy requirements. They argue that job aids "can be made to impart knowledge and to permit the accumulation of experience with the intention of facilitating achievement of specific career plateaus." These investigators suggest a number of ways in which JPA's might be improved to be more useful at different experience and aptitude levels. Progress here would alleviate one of the problems with JPA's. Experienced personnel do not need or like the detail

that is required by the inexperienced. The level of training and experience of the personnel that will be using the aids is an important and recognized input to the process of JPA development, but there has been little attention to a single aid or set of aids for use by technicians of different skill levels.

In connection with this research Navair plans to conduct a field test in 1973 comparing an MDC that was prepared for the AWG-10 avionics system by Westinghouse with an innovative aiding concept that has emerged from the research. The study will use both specialists and apprentices and will attempt to relate experience level to the effectiveness of each aid.

NCN DOD DEVELOPMENTS

An attempt was made to assess non-DOD efforts in the job aid field. There are a number of instances where highly proceduralized aids are used in production but their use in maintenance does not seem to be widespread. Of a number of electronics companies contacted only Motorola appeared to have adopted job aid concepts in maintenance. They use symptom charts, functional block diagrams and logic-trees in their television manuals and in some cases use JPA-like step-by-step procedures.

Of great interest is the use of the general job aid concept among the airlines. Douglas, Lockheed and Boeing have each, for their jumbo jets, developed job aids

for flight line maintenance. The Douglas system for the DC-10 is called FEFI/TAFI (Flight Environment Fault Indication/Turn Around Fault Isolation); the Lockheed L-1011 system is FIRM (Fault Isolation Reporting Method); and the Boeing 747 system is MRS/SRM (Malfunction Reporting System/Specific Repair Methods). Each method involves the assignment of a code to a particular pattern of symptoms as it appears in the aircraft. This code can be radioed ahead and related to the ground portion of the documentation, which contains procedures for isolating the fault. The FEFI/TAFI material, the only material examined by the writer, appears to be similar to the JPA as developed by AFHRL but prepared for a higher experience level. Just how extensive an analysis was performed is not clear. Douglas reports that all the troubleshooting information is being included in TAFI but they are limiting the FIFI portion to critical functions that involve cockpit indicators so that the flight engineer will not be burdened with excessive documentation.

A number of airlines were contacted concerning their impression of the three systems. Most of the airlines used the system as furnished by the manufacturer. At least in the Douglas case, there is little choice since FEFI/TAFI is the troubleshooting portion of the documentation. The most frequent criticism involved the symptoms coding. Many common problems don't have codes. The airlines

recognize that the system can be and is being improved as flight experience is gained, however. Another concern is that flight engineers don't always have time, or take time, to do the coding. There was no indication that the technique has led to the use of less skilled personnel, although one statement was made that mechanics not familiar with the airplane found it helpful, particularly the unit location information.

In their literature Douglas (Adams and Boyer, 1970) asserts that FEFI/TAFI represents a 90% improvement in accuracy and that fault isolation time is decreased by more than 66%.

DISCUSSION OF PERFORMANCE AIDS

DIFFICULTY OF COMPARATIVE STUDIES

Most of the evidence on the effectiveness of job performance aids has derived from comparisons with "traditional" documentation. It has been well established by surveys (Folley and Elliot, '767, Serendipity, 1969) and observations in the field that technicians often do not use technical manuals, even when available, in carrying out maintenance functions. Thus, the studies cited above (with two exceptions discussed below) were comparisons of JPA's vs the normal behavior of experienced personnel which often meant performance without documentation.^{1/} A serious implication of this is that it is not known whether the experimental aid being tested was the cause of the demonstrated improvement or whether improvement occurred because technicians performing with the aid had relevant and accurate information available in some form.

The Naval Air Systems Command's Maintenance Information Automatic Retrieval System (MIARS) incorporates a number of features that will increase the utility of traditional documentation. It is a microfilm system that will utilize reader-printers and have the capability of producing hardcopy manuals. The content of the system is being developed under a "work package" concept that includes some of the features found in

^{1/}The studies also, of course, involved the use of inexperienced technicians: this will be discussed later.

the new aids. Planned for inclusion are simplified Maintenance Dependency Charts, the principal feature of SIMMS and the troubleshooting portion of PIMO, and logic flow charts. Work packages are to be approximately 30 pages in length and are to contain all needed information, including Illustrated Parts Breakdowns, parts lists and support equipment needed for a particular task instead of having these data scattered among several documents. An advanced system for updating is also planned and in the process of being procured (TRUMP - Technical Revision and Update of Manuals and Publications).

Probably everyone associated with the maintenance documentation problem would agree that the above approach would be an improvement. But how close to "optimum" is such a system? One feature that would probably improve MIARS is random access coding of the microfilm version of the documentation. The Navy asserts that the coding and the requisite sophisticated readers are too expensive and that, with the work package organization of data, random access will not be required. The McDonnell-Douglas "WSMAC" (Weapons System Maintenance Action Center) now in operation at the St. Louis plant is a binary-coded access system with logic tree troubleshooting and fault isolation aids. It was reviewed by the Navy MIARS people and rejected as too expensive.

The multipurpose technical documentation system that has come about (one hesitates to say evolved) since before World War II is inadequate for many reasons - inaccurate, usually

obsolescent, often incomplete, so bulky and organized in such a fashion that it is used in the field only as a last resort. It can hardly be characterized as a system that only needs to be fine-tuned. Consequently, it is difficult to assess the improvement that will result from the changes, such as MIARS, that are now being introduced by the Service.

Do these rather conservative changes (which are, in one form or another, also present in the "new" job aids) account for the improved performance of experienced technicians when they use the new aids? To cite a specific, one research investigator conjectures that the efficiency of the PIMO approach probably is due to the use of readability standards and human factors task analysis, features that should be and sometimes are included in conventional documentation (Booher, 1972).

Some of the comparative studies have included an effort to insure that the conventional documentation was accurate, but to the writer's knowledge there have been only two studies where the reference system of documentation while still "conventional" has been brought up to the standard of the experimental system in terms of accuracy, completeness, compactness and readability, characteristics obtainable within the evolving conventional system. One of the exceptions was the AFHRL study which compared fully proceduralized JPA's and conventional documentation on the Maintenance Task Simulator (MTS-2) (Elliott, AFHRL-TR-68-1).

Here, TO-like documentation was produced, since manuals did not exist, which included schematics, theory of operation, system geography information and voltages, resistances and waveshapes at selected points. In the other study, Serendipity's F4-J experiment, a deliberate effort was made to optimize the conventional documentation. Relevant portions of the manual were collected for each maintenance action, checked for accuracy and conveniently packaged. As indicated in the discussion of the experiments, the JPA's were still superior.

The above discussion should not be construed as a recommendation that DOD be satisfied with the small steps that are being taken to improve maintenance documentation; there is a clear need for better manuals in general but it is not yet clear which of several alternatives will best serve the experienced technician.

While the evidence with respect to job aids for the experienced technician is equivocal, such is not the case with less experienced or apprentice personnel. In all of the experiments and field tests, inexperienced technicians performed better with fully proceduralized aids than with conventional documentation. Often, particularly in troubleshooting situations, the inexperienced technicians, even those who had attended the prescribed schools, were unable to perform at all using conventional manuals. However, they were able to perform with minimal errors using the aids

and their time to repair approached the time experienced technicians required when the latter used either conventional or experimental documentation.

There is no reason to believe that documentation improvements now being made will effect any significant change in the performance of the inexperienced technician. It is true that step by step procedures are included in manuals for some maintenance tasks and would presumably be at hand in the improved conventional manual; however, they are not ordinarily based on a task analysis of the type needed and are not explicit and detailed enough to be used by the novice without guidance from an experienced technician. Considering the overwhelming evidence from the experiments and field tests cited above, it is the writer's conviction that non-troubleshooting fully proceduralized job performance aids should be produced and widely used. Such an action would result in significant savings in the cost of maintenance in that the Services would be able to use more effectively the new technician who, although he has presumably been properly trained, spends many months on the job before he performs any but the simplest tasks. Even granting that JPA's may be somewhat more expensive to produce, (an issue treated later) the savings due to more effective use of new technicians would be significant over the life of a new weapon system.

INSTITUTIONAL CHANGE PROBLEM

Achieving efficient cost effective maintenance is a system problem involving management procedures, procurement methods, maintenance philosophy, and training and personnel practices. The system includes a number of well established institutions with all of the problems inherent in a complex process that has developed over a long period of time.

Perhaps the major institutional problem is the relation of life cycle cost and the system acquisition process. Inadequate weight is given to the potential cost savings in maintenance during the initial decision on what kinds of documentation to procure for the new system. Another part of the problem is in the contractor side of the documentation community. Traditional documentation is understood; it is easier to estimate and produce. Given the low priority and status documentation activities have inside the major weapons system firms, it isn't surprising that there is little pressure for change. It seems evident that the impetus for change will only come from those having broad enough responsibility to be concerned with the whole life cycle process.

PERSONNEL AND TRAINING IMPLICATIONS

In addition to the benefits derived from less costly maintenance and improved equipment reliability, job aids offer the possibility of greatly reducing training costs. In general each of the Services follow the same approach



leading to the assignment of a man to an organization level maintenance position where he is concerned with a given system, for example, an electronics system. After basic training, the individual is sent to a school and given an extensive course in basic electronics with emphasis on general theory. He subsequently receives shorter training in the theory and maintenance of a particular system or systems for a total of 30 or 40 weeks of formal training. He then is assigned to a maintenance organization, and is supposed to be capable of productive work with, of course, the assumption that he will be given additional training through OJT. Many experienced observers indicate that in practice the system doesn't work this way. The new technician is unable to use the conventional manuals and must be closely supervised if he does any but the most mundane maintenance task. Since on the job training is often inadequate he learns only if he is highly motivated and working with experienced personnel willing and able to teach him. Given the reenlistment rate (currently 11% for AF Electronic Technicians) and the length of training, the cost of effective maintenance finally obtained from this process is extremely high. The JPA and training research literature is replete with studies indicating that even lower aptitude men can carry out non-troubleshooting maintenance tasks with minimal training if they are furnished with properly prepared job performance guides. If no change were made in formal

training and personnel procedures, significant improvement would still result from providing the newly assigned technician JPA's, if only on selected subsystems, since he would immediately be able to be productive.

Even greater economy would result if the training procedures were changed. With four to six weeks of training in the use of tools and support equipment the average recruit should be able to perform useful work using JPA's (Foley, 1972). There would be substantial and valid objections if this were the only change made. Even though the evidence indicates new technicians derive a good deal of job satisfaction from actually doing productive work with JPA's, effective OJT must be provided if they are to remain motivated and to increase their effectiveness. With the exception of some of the earlier studies (Forecast, JOBTAIN, etc.) job aids design has not included training objectives. A number of studies (PIMO, F4-J Study, HRL Study) indicate that training nevertheless does occur. Research by Post and Price indicates that modified JPA's can be an effective OJT vehicle, one that would be relatively independent of the teaching abilities and inclinations of the personnel ordinarily charged with OJT responsibility (Post and Price, 1972). While training-oriented JPA's would probably be more effective than the usual OJT, additional provisions would be needed for career progression for those technicians exhibiting the talent and motivation

for advancement. Such personnel, should they choose to reenlist, could be sent to school after a tour of hands-on maintenance experience, a system used by the British Navy (Huggett, 1970). Technicians who do not stay in the service would likely enter civilian life better trained than under the present system since they now retain little or nothing of the original formal training received before beginning their military maintenance careers and spend a relatively short time actually at work.

Another problem with the current training and assignment philosophy is the difficulty and expense of cross training. Foley (Foley, 1972) points out for example that there are 34 systems that are the responsibility of Air Force Specialty codes 328X4 (Avionic Inertial and Radar Navigation Systems Specialists). The formal training for this career field is 37 weeks long with 24 additional weeks of OJT. After this training the technician is effective only on the system for which he has received OJT. When reassigned, extensive and expensive cross training is required before the technician is again effective. Job performance aids offer the potential for significantly reducing the cost of cross training.

COST SAVINGS POTENTIAL

Hard evidence of the cost savings possible from adopting JPA's is difficult to develop. In the F4-J study (Post, 1970) a simple mathematical model of a work center was built

to explore the manpower utilization implications of introducing job guides for non-troubleshooting tasks. Without job guides 71% of the inexperienced labor is spent observing and assisting experienced technicians. The other 29% cannot be accommodated by the work load. If job guides were used 83% of the inexperienced would be performing maintenance and the other 17% assisting. The availability of experienced technicians for complex work would increase 52%; the maintenance queue would decrease by 25% and the number of maintenance actions failing quality assurance would decrease by 75%.

In the PIMO study system effectiveness estimates were also made. It is pointed out that simply utilizing time now spent in OJT for maintenance using job guides would decrease the time a one term enlistee spends in training by 25%. The improved performance expected with job guides could improve departure reliability by 50-65% and operational readiness time by 38-40%. If such performance measures were kept at pre-PIMO levels, a reduction in unscheduled maintenance manpower of 30-39% would be possible.

Should JPA's be widely adopted and formal technical training reduced, very significant savings could be made in training costs. The PIMO report states that there were in 1969 approximately 5,700 aircraft mechanics assigned to flight line maintenance of the C-141A. Assuming only 1,000

new men per year due to turnover, and a per man cost of \$3,500 for OJT and \$4,500 for formal training, over \$7,000,000 per year could be saved in this specialty by cutting training from 28 to 4 weeks.

About one-fourth of total DOD enlisted strength is in maintenance. Of this force of about 600,000 more than one-fourth, or 150,000, must be replaced each year because of turnover. If the PIMO calculations are extended to this entire maintenance force the savings would be nearly \$1.2 billion per year. Such an extension is probably not warranted since JPA's are not appropriate for every maintenance task. On the other hand, this is only the potential cost benefit from reducing training and does not include the benefit from better equipment availability and fewer zero defect removals.

If these studies are at all reasonable the cost benefit potential of JPA's is indeed very large, but it is obtainable only by making changes that cut across the decision making structure of the services and by making investments that do not clearly accrue to the benefit of the investing agency.

One objection to JPA's has been that they cost more than conventional documentation and that project managers faced with competing requirements resist their adoption. If the cost savings potential of JPA's is even a small fraction of what is claimed by proponents, the initial cost should not be an overriding factor. A budget quotation

submitted to AFLC in 1971 for completion of flight line JPA's for the C-141 was \$1,300,000 with troubleshooting aids and \$800,000 without (Ostrominski, 1972). McDonnell-Douglas reportedly estimated that JPA's for the F-15 would cost \$45 million versus \$35 million for conventional documentation.

Most estimates indicate the cost at 100% to 125% of conventional documentation. In at least one case, Seek Point, JPA cost estimates were less than the estimates for conventional manuals.

If JPA's were widely adopted the production costs would undoubtedly come down. Current JPA estimates from contractors accustomed to producing conventional manuals are probably inflated because of uncertainty. The industrial base for this kind of product would expand although fortunately there are currently at least a half dozen contractors who have demonstrated capability in this area.

TASK ANALYSIS

Another problem associated with acceptance of JPA's is that it is not generally recognized that performance aid development is an evolving technology and that today's aids are improvements over earlier ones. PIMO, perhaps the widest known and around which there has been controversy, started in 1964. Since then the process of performing maintenance task analyses has been formalized with a consequent improvement in the resulting product. Job or

task analysis is an old concept which has been used for a variety of purposes. What is labeled task analysis can vary from the superficial survey to the most thorough and detailed analysis of the factors that influence how a particular task is done. The JPA task analysis is of the latter type. Some of the factors that are included are the type of equipment, the level of maintenance to which tasks are assigned, the type of test equipment, the aptitude of the user and what he is expected to have learned during training. These factors are included in present procedures such as the Army's Maintenance Engineering Analysis. The emphasis in the task analysis, however, is not on what is to be done to the equipment but on how the technician is to do it.

In order to insure that the delivered product is complete and accurate, Air Force Systems Command has developed a specification, Mil-J-8332 mentioned earlier, which requires certain subproducts, such as a task inventory, that are meant to insure the quality of the final product and which can only be produced if the detailed task analysis is performed. Some of the JPA's that are well known and that have influenced the acceptability of the approach, such as those for the UH-1H, were produced before this specification was developed. It is expected that the specification and accompanying handbooks will improve the quality of JPA's. Another specification, Mil-J-38800, which has been developed by

AFLC, does not require the subproducts and thus does not require detailed task analysis. The writer is in agreement with the proponents of JPA's that products procured using this specification, while having the same format and appearance, will not be as effective as those based on task analysis since even small errors can render the aids virtually unusable.

NEED FOR DEFINITIVE DEMONSTRATION

Considering the potential of maintenance aids for less expensive maintenance, better equipment availability and better manpower utilization it is difficult to understand why more money has not been spent in bringing this approach to a point where a clear-cut decision as to its merit could be made. The PIMO project cost \$2.8M. All of the AFHRL effort on JPA's since 1960 cost a total of \$540K. The early Army HumRRO work on performance aids was estimated to be less than \$1.0M. The Navy expenditures on research in the area are about \$500K to date. Thus approximately \$5M has been spent developing and evaluating something that shows promise of saving many times that amount annually.

The numerous small research studies over the years have not had the influence that maintenance aid proponents have hoped for. Because of the general difficulties surrounding human factor field research and the small sample sizes found in the aid studies, a number of doubts remain, particularly in the troubleshooting area. There are

differences of opinion even among job aid proponents about the optimum way to present maintenance data and there are a number of issues needing more study, some of which have been discussed in this report.

In the writer's opinion it is time to "freeze the design" and demonstrate the product. A large scale series of well-planned field demonstrations of job aids should be made with the active involvement of all parties concerned with maintenance documentation. These should be funded well enough to insure that the results will be compelling and if positive will lead to acceptance and implementation.

The Air Force Human Resources Laboratory has proposed in Project Innovate (Project 1194 of Program Element 63102F) an effort which, with some modification, would serve part of this purpose. This project, which has not been funded, would compare conventional technical orders, SIMMS or MDC type decision aids and fully-proceduralized JPA's and would provide answers to the questions of whether brief technical training is adequate with JPA's and whether JPA's alleviate the cross-training problem within a specialty. It would also compare performance of personnel of differing aptitude levels.

The project would consist of a number of phases: development of JPA's for all or at least a representative subset of equipments maintained by personnel of one electronic

Air Force Specialty Code (AFSC), the development of short simplified training programs to accompany the aids, the development to job-task performance tests to be used in evaluation, and the conduct of controlled experiments and demonstrations. As indicated earlier a preliminary try out of aids and a training program for the AN/APN-147 doppler radar and its computer, the AN/ASN-35 was held in 1972 at Altus Air Force Base. Using these equipments the first controlled experiment will compare, at the organization and intermediate levels of maintenance, fully proceduralized aids, SIMMS decision aids and technical orders. A later experiment will determine whether men briefly trained to use JPA's on one equipment can effectively maintain unfamiliar equipment in the same AFSC using JPA's. A positive finding here would have great significance since technicians must currently be given extensive OJT on the new equipment before they are effective even though they have been given formal theoretical training to make the transition easy. These demonstrations will be evaluated on a number of criteria: performance on job task performance tests (not paper and pencil theory tests), spare parts consumption, manpower requirements and training costs. The Air Force plans to use different contractors for conducting and evaluating the demonstrations. The total program will extend over five years and will require approximately \$2.0M as currently planned.

In the writer's opinion this program should be accelerated so as to be completed in three instead of five years. The effort is structured such that part of it could be done in parallel without risk. It is also recommended that more subjects be used and that the logistics community be included in the design and execution of the demonstration so that it will have maximum impact.

It is hoped that this scale of effort will also be carried out in the Army. Their planned program to develop and demonstrate information presentation methods tailored to various commodity groups will provide additional focus on the documentation problem.

INFORMATION PRESENTATION MEDIA

Up to this point this report has been primarily concerned with the content and, to a lesser extent, format of maintenance documentation. The methods of presentation to the user, including methods of keeping the material current, are also important. This is particularly true for major problems in maintaining up to date information and accessing the material needed to troubleshoot and repair complex subsystems.

There have been numerous DOD and industry studies of documentation and while most of them have been concerned with management problems some have concerned themselves with method of presentation, one of the most recent being a NSIA study for the Air Force (NSIA 1972) which recommended the use of microfilm for documentation, including flight line maintenance.

Although no attempt will be made here to review these studies, a few general comments can be made. Each of the services is moving to microfile systems of one sort or the other. Considering industry experience, for most applications the conversion can be justified on economic ground alone even if nothing more is done than copy the existing manuals. Much of the potential of microform will of course not be realized if this is all that is done. The MIARS system which has been referred to earlier is an attempt to gain more benefit by reorganizing and indexing the material and

by providing for rapid up-dating. The SAFEGUARD MDS not only does this but also incorporates fully proceduralized aids. Such systems are well within the state-of-the-art.

The USMAC system developed by McDonnell Douglas as a candidate for F-15 technical documentation is a binary coded microfilm system which includes trouble shooting trees and symptom indexes as well as conventional documentation. Although this system was not accepted for the F-15, it is in use at the McDonnell Douglas plant at St. Louis for acceptance testing and trouble shooting on new aircraft. It currently contains a large fraction of F-4 technical manual materials. The binary code access permits heirarchical retrievals on materials related to a subsystem or component to the depth desired.

As mentioned earlier random access coding in MIARS was judged to be unnecessary and too expensive. Should more sophisticated systems be developed? Is there a need for centralized data banks with remote terminals? Considering the potential for improvement in MIARS or MDS level systems and in the updating speed and accuracy that computer output microfilmers will make possible, it is doubtful that centralized data banks and remote terminals will be needed to provide maintenance data that is sufficiently current. There may be economic benefits, however, that should be explored.

There are other reasons however to consider central data banks with remote terminals. The possibility of the maintenance

man being able to interact with a computer on a real time basis as he troubleshoots deserves investigation. Such a capability could also be used to provide computer assisted instruction (CAI) to maintenance personnel.

Audio-visual systems, often earphones and small slide projectors, have been used successfully for years in manufacturing production lines for presenting assembly instructions.

The few DOD studies in audio visual approaches to presenting maintenance data have not been positive, in part because of the nature of the equipment used. The literature suggests, however, that audio visual presentation of information can be effective providing care is taken in what is presented in each mode (Post and Price, 1972). Recent applications of video tape systems to training have yielded promising results. For example, a series of ten color video tapes each about 20 minutes long has been produced by Learning Achievement Inc. for Burroughs to be used in teaching computer operation and operator maintenance. The system is interactive in that the student stops or rewinds the machine and answers questions in a workbook. The use of such an approach to convey an overall picture of an operation - something a JPA does not do - or to introduce retrofits might be effective.

RECOMMENDATIONS

System Demonstration

There is a need for a program of definitive demonstrations to settle the main issues in the area and to provide the needed impetus for implementation of those features that are effective in a real operating environment. The needed demonstrations should be conducted with each of the military departments being involved.

(1) The proposed but unfunded Air Force project "Innovate" should be enlarged and carried out. This project will compare conventional technical orders, decision aids and fully proceduralized job performance aids (JPA's) and will provide answers to the questions of whether brief technical training is adequate with JPA's and whether JPA's alleviate the cross-training problems within a specialty.

(2) The Army's "Low Cost Ownership" Program on the improvement of military technical information transfer methods should be supported and funded as a three year experiment. This effort will analyze information presentation approaches in terms of their application to commodity groups - aircraft, combat vehicles, etc. - and will select the best approach or combination of approaches for each commodity group. Packages will then be demonstrated for several military occupational specialties for maintenance up through the depot level.



(3) The Naval Air Systems Command's MIARS and TRUMP systems should be accelerated and considered for Navy-wide use. MIARS is a microfilm system with hard copy compatibility that involves the reorganization of technical data into "work packages" that cut down the time that technicians must spend searching through manuals. It offers the capability of being the vehicle for introducing improvements in content such as job performance aids, once these improvements are accepted. TRUMP is a system now in procurement for automatically updating MIARS.

Management:

(1) Focal points should be designated in OSD and in each of the military departments with responsibility to deal with the R&D, systems, logistics, and training efforts needed for the large scale demonstration program.

(2) There should be fiscal visibility and management focus for the R&D program for maintenance aids. A Program Element should be established for each military department to consolidate the efforts.

(3) In order to coordinate the overall DOD efforts, there should be a tri-service review of current activities and plans in the maintenance aid area. A committee should be formed or an existing one directed to review the ongoing activity, particularly the planning of major demonstrations and the utilization of the results of those demonstrations.

Formulation of an ARPA effort similar to the CAI program initiative should be considered.

(4) For an interim period of two to three years, OSD, specifically OSD (I&L) and DDR&E, should review the maintenance aids approach and funding proposed for new weapon systems and should stimulate the application of innovative approaches and funding support for these.

(5) The military departments should initiate analyses on the economics of production and utilization of improved maintenance aids. These should include the comparative costs of alternative format and content (e.g., JPA's, SIMMS, conventional manuals) as well as media (books, microfilm, video cassette).

(6) DOD should institute, through the military departments, an analysis of the costs of improper maintenance (to include such factors as fake removals, spares, shipping, etc.). This data should be included in a broad analysis of the economics of applying better maintenance aids and information systems - to include training costs, personnel costs, and equipment costs.

Systems Application:

(1) Non-troubleshooting fully proceduralized job performance aids -- job guides -- should be developed for all new weapons systems. These will be primarily oriented to

routine maintenance tasks. This should be done in accordance with specifications requiring task analysis.

(2) Job guides should be developed for selected portions of systems now in the inventory, based on a review of high cost areas.

(3) Information systems other than books such as audio-visual cassette and film systems to provide system overviews, to introduce equipment modifications and to explain difficult procedures should be applied.

(4) For major weapon systems, microfilm reader printers which include job guide formatted materials should be used both for economic update and facility of information access.

Research and Development:

(1) FEFI/TAFI (Flight Environment Fault Indication/Turn Around Fault Isolation), a troubleshooting system for the DC-10, should be examined for possible military application.

(2) Aids useful at different skill and experience levels and aids that have training objectives should be developed. The promising Navy sponsored research on "families of aids" should be extended so that multipurpose documentation suitable for experienced as well as inexperienced technicians can be developed with consideration also given to the inclusion of OJT material.

(3) Computer supported audio-visual presentation systems should be studied as potential sophisticated trouble-shooting aids making possible dynamically optimized trouble-shooting strategies.

(4) Studies should be made of the influence that system characteristics such as modularity or degree of built-in testing have on the type of aids appropriate for a system.

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